XI. DSN Operations

OPERATIONS AND FACILITIES

A. Real-Time Selection and Validation of Telemetry Data in the SFOF, *W. Kinder and W. Kizner*

1. Background

The DSN has the responsibility of delivering to the Flight Project a master data record (MDR) within 24 h after a station track. In the SFOF, the DSN Telemetry Analysis Group determines when gaps or data quality require recall of fill-in recorded data, verifies the quality of the MDR, and coordinates certification of the record with the Flight Project and the DSN Operations Control System. To accomplish this task in real-time, it was decided that DSN partial status, i.e., equipment indicators based on the presence of a signal, would accompany the telemetry data into the SFOF, where the IBM 360/75 computer would utilize these indicators for the generation of an MDR in real-time. However, a problem arises in that some of the partial status indicators from the DSIF are not indicative of the present status of the data, due to their built-in response time delay.

The DSN Telemetry System Design Team conducted a study with the intention of recommending an algorithm for data selection and validation based on these partial status observables traveling with the telemetry data. This article presents an interim algorithm for incorporation into the 1971 era Telemetry System; a presentation of the possible application of discriminant analysis to data validation; and finally, an outline of possible future work with discriminant analysis for the evaluation of these partial status observables.

2. Recommended SFOF Data Selection and Validation Algorithm

The SFOF telemetry processor should select and validate data on the following partial status indicators:

(1) Observe and record data $= F \cdot I \cdot N \cdot \bar{E}$.

F = frame sync acquired, leading and trailing edge.

I = interval timing, SFOF checks on DSIF ground received time.

N = noise with data, telemetry and command processor calculated signal-to-noise ratio estimate exceeding some minimal value.

$\bar{E}$ = no error on GCF service, highspeed and wideband data blocks.

where

Observe = drive display devices in the SFOF analysis and support areas.

Record = on-line data validation recorded on telemetry system data record.

Recall = post-track replay of facility analog, digital records.

(2) Observe and recall data = any one or all of the above observables in default.

On the selection of a data stream, the SFOF telemetry processor should function automatically. Rankings of signal-to-noise ratio estimates, transmission errors, and errors in the frame synchronization word are available for selection decision. If two or more identical data streams from a common spacecraft are equal in all observables, then the selection automatically favors the rising deep space station. The selection functions can be manually overriden and forced to favor a particular deep space station. All of the incoming data streams from a particular spacecraft, whether selected to drive display devices or not, are logged in the SFOF. Once a data stream is selected, the other streams are inhibited from driving the display devices.

The values, or favored states of these partial status indicators, are supplied by the DSN/Project and initialized manually in the SFOF before a track by action on the part of the DSN Telemetry Analysis Group. During a track, real-time changes to the partial status standards, as when going from a coded to an uncoded mode, are handled by this same Analysis Group as real-time Telemetry System standards and limits changes coordinated with the DSN Operations Control System. As shown in Fig. 1, the validation routine should be identical for either real-time telemetry or recall data.

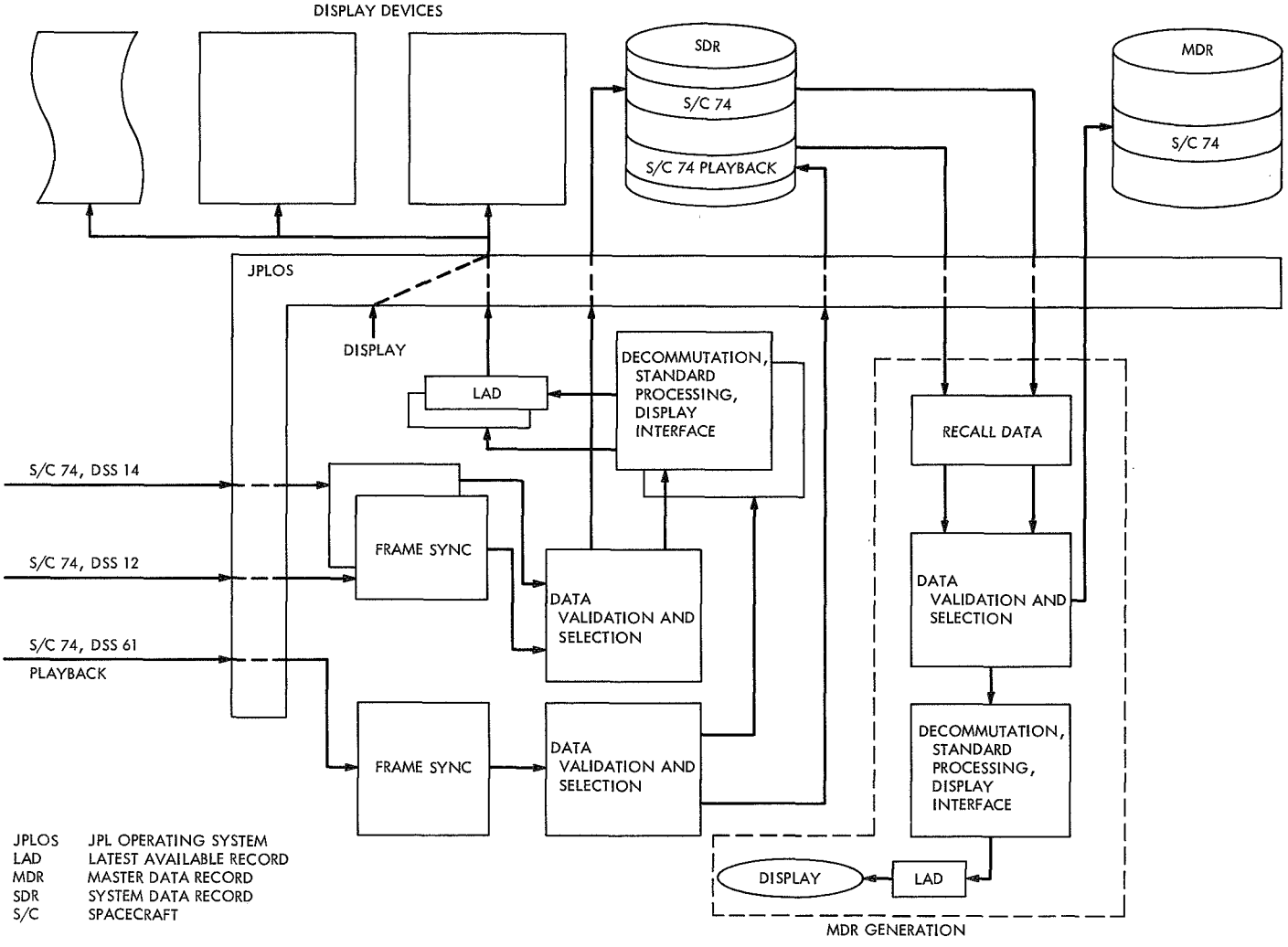

Fig. 1. SFOF telemetry data validation and routing

When a default condition is experienced, the data stream should not be inhibited automatically; however, the SFOF telemetry processor should alarm the Analysis Group with the following message:

(1) Time of outage, full sync frame prior and after bad data.

(2) Display of latest available applicable partial status information, including all lock indicators in the telemetry high-speed data blocks.

(3) Data identification, type, station, spacecraft, bit rate, recall/real-time.

This alarm routine should be the basis for a future, fully automatic telemetry recall capability.

Whenever the aforementioned validation function is overridden, the processor should tag all accumulated data during this condition as "observe and recall." Supplementary analog records are available for the Project for non-real-time processing. In the SFOF processor's periodic (hourly) and post-track telemetry summaries for the Analysis Group, the data outages should be tabulated. Based on SFOF outage time, partial status indicators, and delay characteristics inherent in their design, the Analysis Group should specify standardized replay times for recalling data from the various digital and analog facility logs.

Data selection and validation should be based on data time progression and data word repetition in the telemetry stream. This process should be automated in keeping with the DSN requirement of delivering an MDR within 24 h after a track. Manual intervention should be limited to system initialization and possible post-track recall of facility logs. Alarms to the Analysis Group should be a minimum in keeping with the Group's response capability.

3. Application of Discriminant Analysis to Data Validation

A method of combining measurements to differentiate between two (or more) alternatives is called discriminant analysis. Here the two alternatives are whether the data is good or bad. Let k be the number of measurements on which a decision is based.

In order to make use of these measurements, some knowledge of the kinds of measurements which occur for each alternative is needed. If the probability distribution of these measurements for each alternative were known, a standard procedure would be to employ the Neyman–Pearson likelihood ratio criterion (Ref. 1) for testing between the alternatives. When these distributions are not known, an applicable technique is the use of discriminant analysis. Under certain assumptions, such as that the distribution for the measurements for each alternative is a k-dimensional normal distribution having the same covariance matrix, the method of discriminant analysis is equivalent to the use of the likelihood ratio.

It is convenient to define scatter, which is related to the variance of the distribution. Let $(X_1, X_2, \cdots, X_n)$ denote a sample from a one-dimensional distribution with a cumulative distribution function $F(X)$. The scatter $S_{X_0, n}$ of the sample about the pivotal point X is defined by

$$S_{X_0,n} = \sum_{i=1}^{n} (X_i - X_0)^2 = S_{\bar{X},n} + n(\bar{X} - X_0)^2 \qquad (1)$$

where $\bar{X}$ is the sample mean. Thus, the scatter of a sample is a minimum when taken about the sample mean.

It is assumed that a sample of the measurements for each category is available; the sample represents previous cases when the measurements were made. It is required to find some single linear combination of these variables Z such that the scatter of Z between the means for each sample is as large as possible relative to the sum of the internal scatter of Z for each sample. This is roughly equivalent to finding a linear combination of variables such that the square of the difference of its expectation in the two populations is maximized, subject to the condition that the sum of the variance for each sample is a constant.

An exact statement and solution of this problem will now be given. Suppose

$$(X^{(\gamma)}_{1\xi_\gamma}, \cdots, X^{(\gamma)}_{k\xi_\gamma}, \xi_\gamma = 1, \cdots, n_\gamma), \qquad \gamma = 1, 2$$

where $n_1 > k, n_2 > k$ are two samples with k variables. Let $(\bar{X}^\gamma_1, \cdots, \bar{X}^\gamma_k), \gamma = 1, 2$, be the vectors of means. Let the matrix $\|\mu^\gamma_{ij}\|, \gamma = 1, 2$, be the internal scatter matrices defined by

$$\mu^{(\gamma)}_{ij} = \sum_{\xi=1}^{n_\gamma} (X^{(\gamma)}_{i\xi} - \bar{X}^{(\gamma)}_i)(X^{(\gamma)}_{j\xi} - \bar{X}^\gamma_j) \qquad (2)$$

Let $(\bar{X}_1, \cdots, \bar{X}_k)$ be the vector of sample means, and $\|\mu_{kj}\|$ the internal scatter matrix of the ground sample composed of the two samples pooled together. Let

$$Z^{(\gamma)}_{\xi_\gamma} = \sum_{i=1}^{k} C_i X^{(\gamma)}_{i\xi_\gamma}, \xi_\gamma = 1, \cdots, n_\gamma, \qquad \gamma = 1, 2 \qquad (3)$$

Then $(Z_1^{(1)}, \cdots, Z_{n_1}^{(1)})$ and $(Z_1^{(2)}, \cdots, Z_{n_2}^{(2)})$, except for scaling, are one-dimensional samples. Let $\bar{Z}^{(1)}$ and $\bar{Z}^{(2)}$ be the means of the two samples of Z's and $\bar{Z}$ the mean of the pooled samples. Let

$$S_W = \sum_{\gamma=1}^{2} \sum_{\xi_\gamma=1}^{n_\gamma} (Z_{\xi_\gamma}^{(\gamma)} - \bar{Z}^{(\gamma)})^2 \tag{4}$$

$$S_B = \sum_{\gamma=1}^{2} n_\gamma (\bar{Z}^{\gamma} - \bar{Z})^2 \tag{5}$$

It will be noted that, if S is the scatter of the grand sample obtained by pooling the two samples of Z's, then $S = S_W + S_B$. S_W is the within sample component and S_B is the between sample component of S. The basic problem is to determine $(C_1, \cdots, C_k)$ so as to maximize S_B for a fixed value of S_W. The solution is given by the following theorem, whose proof can be found in Wilks (Ref. 1).

THEOREM. *Let $\|\mu_{ij}^W\|$ and $\|\mu_{ij}^B\|$ be within sample and between sample scatters of two samples from a k-dimensional distribution where the sample sizes both exceed k and where $\|\mu_{ij}^W\|$ is positive definite. Let S_B and S_W be defined as in Eqs. (4) and (5). The value of $(C_1, \cdots, C_k)$, say $(C_1^1, \cdots, C_k^1)$, which minimizes the ratio*

$$Q = \frac{S_W}{S_W + W_B} \tag{6}$$

so that S_W has a fixed value $C \neq 0$, is the solution of

$$\sum_{j=1}^{k} (\mu_{ij}^B - l_1 \mu_{ij}^W)\, C_j = 0, \qquad i = 1, \cdots, k \tag{7}$$

where l_1 is the non-zero root of the characteristic equation

$$|\mu_{ij}^B - l\mu_{ij}^W| = 0 \tag{8}$$

given by

$$l_1 = \frac{n_1 n_2}{n_1 + n_2} \sum_{i,j=1}^{k} \mu_W^{ij} (\bar{X}_i^{(1)} - \bar{X}_i^{(2)})(\bar{X}_j^{(1)} - \bar{X}_j^{(2)}) \tag{9}$$

where

$$\|\mu_W^{ij}\| = \|\mu_{ij}^W\|^{-1} \tag{10}$$

Thus, the vector $(C_1, \cdots, C_k)$ can be determined and used to differentiate or discriminate between two alternatives. Furthermore, the minimum value of Q is $1/(1 + l_1)$.

These equations have been programmed and checked. One check on the accuracy of the computation is to calculate Q by means of Eq. (6) and $1/(1 + l_1)$, and to compare the results. The two values have agreed to about seven places in all the cases that have been run.

One problem which may occur is the case where $\|\mu_{ij}^W\|$ is very nearly singular and cannot be inverted. This condition can be determined by the use of the JPL library routines which calculate the singular value decomposition of matrices. It can readily be seen that $\|\mu_{ij}^W\|$ will be singular if one or more variables are given as a linear combination of the others. Conversely, if $\|\mu_{ij}^W\|$ is singular or very nearly singular, then the data is consistent with the hypothesis that one or more variables are given as linear combinations of the others. In this case, nothing is lost by eliminating those variables which are linear combinations of the others. To do this, the singular value decomposition is used to determine which variable should be eliminated so that the resulting matrix $\|\mu_{ij}^W\|$ with one less variable should have the best condition number.

For these matrices, the condition number is equal to the ratio of the largest to the smallest eigenvalue. This procedure may be repeated any number of times until a well-conditioned within-scatter matrix results.

To implement this method, one needs past histories of indicators or measurements for good and bad telemetry data, from which the means and $\|\mu_{ij}\|$, $\|\mu_{ij}^W\|$, and $\|\mu_{ij}^B\|$ can be calculated. Then the theorem is used to calculate the linear combination determined by $(C_1, \cdots, C_k)$. If necessary, some variables may be eliminated if they appear to be linear combinations of others.

4. Future Work

Some of the partial status observables are redundant for this application. Some, because of their time response, are meaningless. We still need data on how these indicators, when displaying outages, propagate through the Telemetry System. We also need data on how the fixed observables, such as measured signal-to-noise ratio and errors in the fixed frame sync word, behave as threshold is approached. Tests are planned to acquire field data on the above unknowns and to evaluate the indicators using the discriminant analysis technique.

Reference

1. Wilks, S. S., *Mathematical Statistics*, Sec. 18.7. John Wiley & Sons, Inc., New York, 1962.

B. DSN Tracking System Operations,

J. Heller and R. B. Miller

1. Introduction

The purpose of this article is to describe the operations of the DSN Tracking Operations Analysis Group in the Mark IIIA era. Most of the functions described are being performed at the present time by manual procedures and with the use of the software available on the IBM 7044/7094 computer system. The design of the IBM 360/75 software is geared towards minimizing manual operations in the accountability and validation of tracking data and towards using computer displays to monitor data flow and system performance.

2. Functions

The DSN Tracking Operations Analysis Group performs the following functions:

(1) Monitors the operations of the SFOF portion of the Tracking System editing and validation functions and the DSN Tracking System in general.

(2) Coordinates the tracking editing function and the presentation and display of tracking data.

(3) Monitors the partial status indicators inserted in the tracking data stream and provides regular reports and alarms to DSN operations control.

(4) Generates and provides tracking standards and limits in response to operational and status information received from the spacecraft project and the DSN Operations Control System. These will include such items as predict tolerances, doppler tolerances, and frequency precision tolerances.

(5) Generates tracking prediction information as required, and certifies its availability for transmission. The DSN is capable of generating its own predicts without project inputs, but the project is expected to provide validated trajectories to ensure that the most up-to-date information is used to generate predicts.

(6) Coordinates the tracking calibration function.

(7) Coordinates any orbit determination function which may be necessary for the DSN generation of initial conditions for prediction purposes.

3. Software

The DSN Tracking Operations Analysis Group is the cognizant user engineer for the SFOF Tracking System software. This assignment coincided with the DSN decision to implement configuration C for the *Mariner* Mars 1971 mission. This configuration calls for the DSN Tracking System software to reside in the IBM 360/75 computer while the orbit determination and the trajectory functions are accomplished in double precision on the Univac 1108 computer. An integral SFOF tracking subsystem software design was evolved which operates in real time in the IBM 360/75 under the JPL operating system. Figure 1, a functional diagram of this design, shows the main software elements and data files. A brief description of these components will serve to clarify the diagram.

a. Teletype tracking data input processor (TYDIP). TYDIP is a multimission real-time program responsible for the decommutation and reformatting of tracking data received on teletype from various stations and forwarded by the Univac 490 communications processor. These data will be examined by TYDIP for acceptable format; unacceptable data are stored in a rejected data file; data condition codes and data values are checked to determine that they are within allowable ranges; the accepted data are then converted to DSIF Tracking Subsystem (DTS) format and a subroutine, teletype tracking data outage subroutine, is called to compute sample rates and detect sample rate changes and data outages; a pass identification code is attached to the data stream, which is then routed to the Pseudo-Residual Program.

b. DTS tracking data input processor (DTDIP). DTDIP is a multimission real-time program responsible for the decommutation and reformatting of tracking data and messages received over the high-speed data lines (HSDL). Messages are routed to the DTDOP message processor described below. Tracking data in TTY format are routed to TYDIP for processing, as described above. Tracking data from the DTS, which already contains sample rates and pass identification codes, is simply routed to the Pseudo-Residual Program. Both TYDIP and DTDIP have the same output format.

c. DTS tracking data output processor (DTDOP). DTDOP interprets control messages received from the DTS and composes and transmits over HSDLs appropriate response messages. These include data transmission requests, predict transmissions, predict instructions, etc. In particular, DTDOP detects outages and initiates data recall automatically.

d. Pseudo-Residual Program. This is a real-time multimission program which operates on all incoming tracking data and differences the data from predicts. It interfaces with the Predicts Program to obtain prediction data which

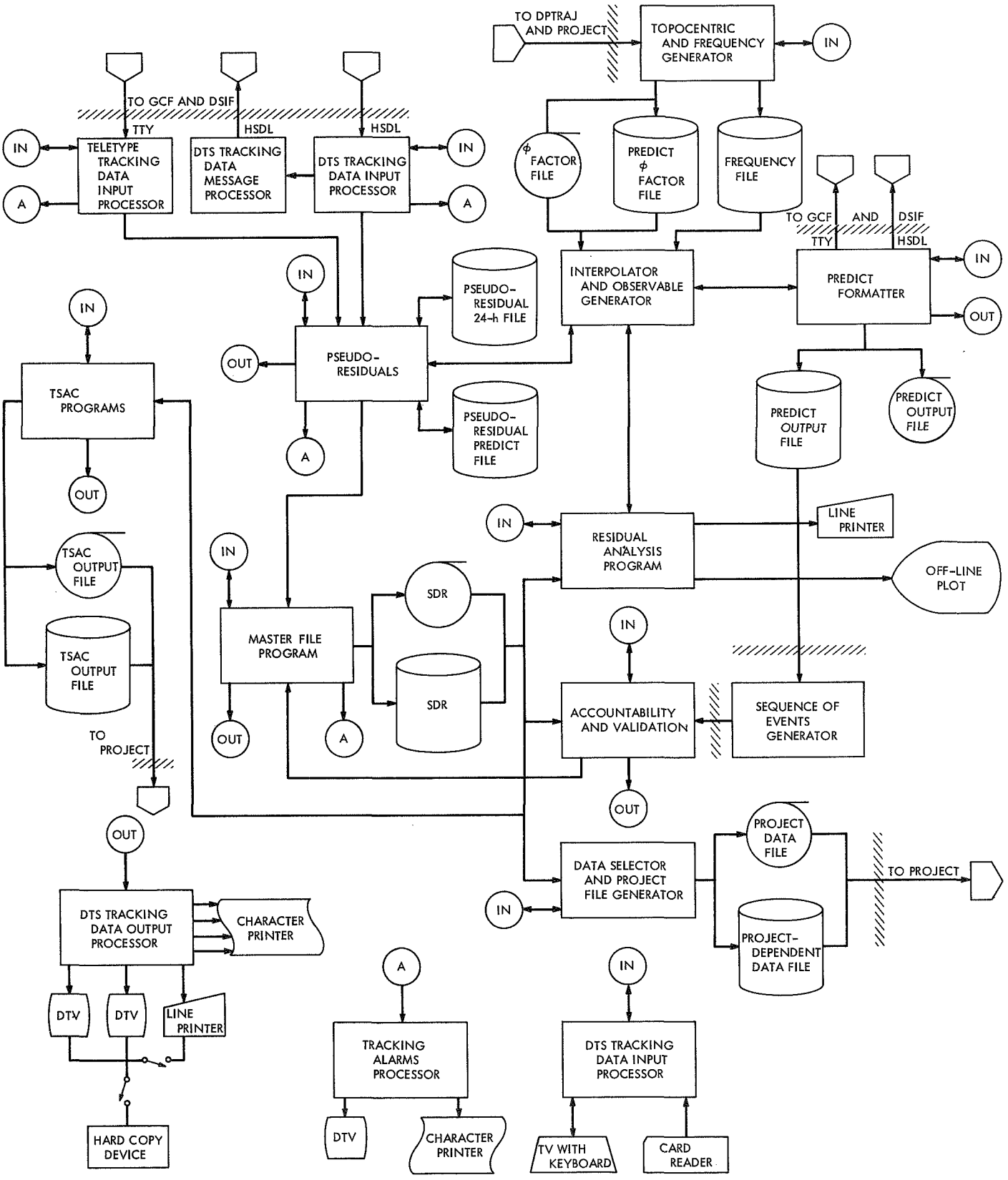

Fig. 1. SFOF tracking subsystem software design

are stored on disk, as described below. It also computes data noise for doppler and ranging data and outputs all these computations as printed listings and for digital TV (DTV) plots. In addition, the program generates a data quality indicator which is placed alongside the non-DTS tracking data (the DTS data has a quality indicator already). All tracking data are then routed to the Master File Program. The last 24 h of pseudo-residual data are stored on disk for analysis.

e. Master file program (MFP). The primary responsibility of the MFP is the creation and management of the system data record (SDR) file. This file contains up to 2 weeks of tracking data associated partial status code and accountability information and resides on disk. The MFP accomplished four main functions:

(1) Processes tracking data received from TYDIP or DTDIP and writes it on the SDR file. Recall data can be merged in time sequence.

(2) Allows the DSN Tracking Operations Analysis Group to add partial status code (such as transmitter on times and frequencies, range bids, etc.) and to perform data editing functions, i.e., delete, suspect, ignore data.

(3) Computes in real time an accountability summary for each pass listing data received, good data received, and percentages for each data type.

(4) Outputs the SDR or portions of it onto tape, transfers it to the Univac 1108 via the electrical interfaces, prints it out on the line printer or displays it on DTV.

f. Accountability Program (AP). The function of the AP is to perform non-real-time accountability on the SDR file. It will compute over any time interval the number of data points, number of good data points, and percentage of good data for each data type, and output summaries on DTV or printer.

g. Tracking alarms processor (TAP). The TAP receives alarms from TYDIP, DTDIP, pseudo-residuals, and MFP. In addition, it receives some status and accountability information from these programs and formats all of this information into a continuous log of alarms and outages. This log is output on a printer sequentially and is displayed on DTV in a special format which is updated automatically to show the last alarm and data status for each data stream.

h. Residual Analysis Program (RAP). The RAP is a non-real-time data analysis program. For an input time interval, it computes data residuals for each data type based either on a set of predicts or on a least squares fit of the data itself. Once the residual set is obtained, the RAP computes upon request the mean and standard deviation of the set, the cumulative residual and the local standard deviation at each point, and the autocorrelation function and power spectrum for the set. The output is available in either printed or plotted form.

i. Tracking system analytic calibration software (TSAC). The TSAC is under the cognizance of the Mission Analysis Division. TSAC consists of two non-real-time IBM 360/75 routines: (1) the platform observables subassembly, which provides calibrations for DSS locations, polar motion, and time, and (2) the transmission media subassembly, which provides calibrations for the troposphere, ionosphere, and space plasma effects, using differenced range versus integrated doppler. This software will be operated by the DSN Tracking Operations Analysis Group and the resulting polynomials will be furnished to the project.

j. Predicts Program (PREDIX). The function of PREDIX is to compute predicted observables for use both in the acquisition of the spacecraft by the DSS and in the validation of the data by the Tracking System. The input to PREDIX is a probe ephemeris tape generated by the Double-Precision Trajectory Program (DPTRAJ) on the Univac 1108. This input is transferred via tape or via the Univac 1108/IBM 360/75 electrical interface. PREDIX then generates for each station a file of angles, range, and range rate (ϕ factors) computations which are stored on disk in the IBM 360/75. The ϕ factor file contains up to 2 weeks of prediction data for each active spacecraft. At the time of transmission, an interpolator and observable generator routine uses a stored frequency file to convert the factors to doppler frequencies and range units interpolated for the desired sample interval and makes these available for transmission by teletype (TTY) or HSDL. The interpolator routine is also accessed by pseudo-residuals and RAP when these programs need predicts. In addition, the program computes and stores a set of view periods for extended periods of time. Predict output is available on tape and DTV. Further interfaces of the program include the tracking simulation program and the sequence of events generator. View periods interface with the scheduling software.

4. Hardware

The DSN Tracking Operations Analysis Group will perform its real-time functions in the SFOF from an area within the Network Analysis Team area. Figure 2 shows

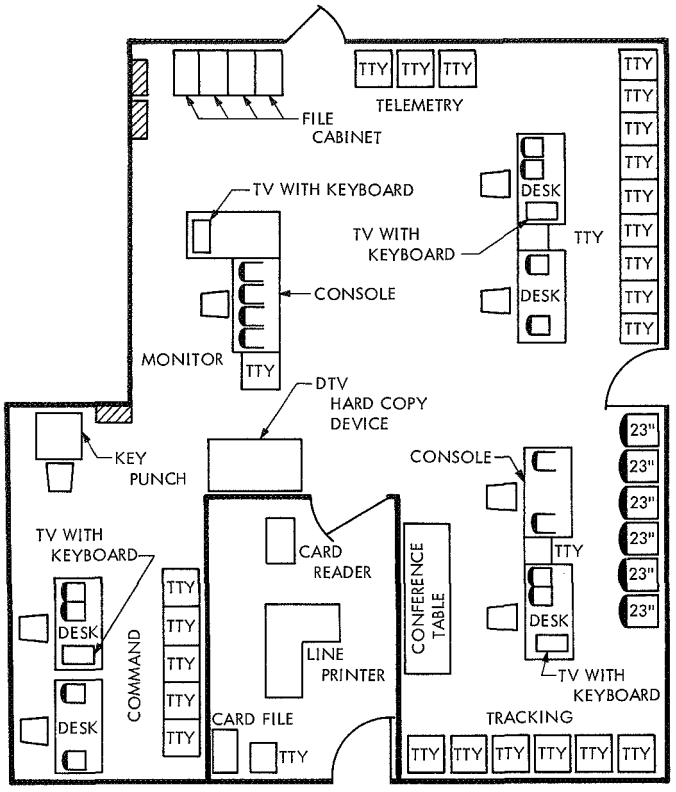

Fig. 2. Tracking Operations Analysis Group area in SFOF

the layout of the area and the hardware complement allocated to support the DSN Tracking Operations Analysis Group. In addition to the desks and chairs, the hardware includes an appropriate operational voice communications system capability and the following input/output devices:

(1) An IBM 2260 with keyboard. This device is an input message processor consisting of a keyboard and a cathode-ray tube display. It will be used for composing most of the real-time input and control messages for the Tracking System software.

(2) A shared IBM 2501 card reader for bulk inputs via punched cards.

(3) Seven TTY printers for display of tracking data, pseudo-residuals, and tracking alarms.

(4) A shared IBM 1443 line printer for bulk listings of tracking data and predicts.

(5) Four closed-circuit TV monitors, which include 3 DTV output channels dedicated to the Tracking System software. These DTV channels will display pseudo-residual plots, tracking alarms, and data summaries. A fourth DTV channel, driven by the Monitor System software, will be dedicated to displaying the tracking system parameters gathered by the Monitor System.

(6) A shared DTV hard copy device which will deliver on request a print of a selected DTV display.

(7) An Olivetti programmed 101 desk top computer to perform spacecraft frequency determinations, blunder point calculations, etc.

5. Operations

The DSN Tracking Operations Analysis Group will maintain its operational position on a round-the-clock basis and perform most of its functions in real time. The operational functions fall primarily in the following areas.

(1) *Tracking data functions.* The group will operate the Tracking System software and monitor the tracking data flow. It will initiate data recall, merge the partial status code into the data, validate the quality and quantity of data on the SDR written 24 h after the end of a tracking pass, transfer the data to the user via the Univac 1108/IBM 360/75 electrical interface, and write the data onto an SDR tape for safekeeping and delivery to the users.

(2) *Tracking system functions.* The group will monitor the Tracking System performance in real time both by the content of the tracking data via pseudo-residuals and by the Monitor System display of tracking parameters gathered throughout the network. The group will alert the Operations Control Team of any malfunction or anomaly and will attempt to isolate the facility involved.

(3) *Predict functions.* The group will be responsible for obtaining the necessary trajectory and frequency information, operating PREDIX, and generating the appropriate prediction data in a timely manner. It will also validate the output before transmission to the station or delivery to the user.

(4) *Tracking system analytic calibrations.* The group will be responsible for gathering the raw data and operating the software for the TSAC function. The resulting calibration polynomials will be validated by cognizant Mission Analysis Division personnel before delivery to the user.

These real-time functions will be backed up with a small amount of non-real-time support dedicated to the in-depth analysis of problems and data, the generation of operating procedures, and the writing of reports.